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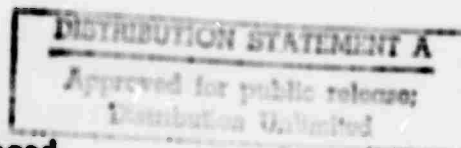
**RESEARCH IN LONG HOLE EXPLORATORY DRILLING
FOR
RAPID EXCAVATION UNDERGROUND**

prepared by

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13. Abstract

A new concept of handling rock drilling tools has been designed. The purpose is to provide a means to drill a four-inch diameter hole 1,000 feet horizontally in moderately hard and hard rock. The hole will be used to probe ahead of tunnel boring machines to sample for rock conditions or hazards such as water or gas.

Equipment is being made and assembled in Burlingame, California for a granite quarry test near Watsonville early in 1972. A hollow spindle rotary drill or skids will permit storing 1,000 feet of 2-3/8 inch diameter flush CD drill rod in one piece in a pipe on the ground behind the drills. This rotates an in-hole percussion device for rapid drilling or a diamond core barrel for sampling.

A special rapid rod extractor, using powered opposing wheels, has been designed and is being made.

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10	KEY WORDS	LINE A		LINE B		LINE C	
		ROLE	AT	ROLE	AT	ROLE	AT
	Rock Drill Tunnel Probe Excavation Underground Diamond Drilling Drill Rod Handling Drill Instrumentation						

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SEMI-ANNUAL REPORT

1.0 SUMMARY

This is the semi-annual report for Contract H0210037. This one-year contract dated February 26, 1971 is for the development of a horizontal drill for probing ahead of a tunnel-boring machine (TBM) for rapid excavation underground. This contract is being administered by the U.S. Bureau of Mines and is sponsored by ARPA. It is a cost-plus fixed-fee contract for approximately \$59,000 of which about \$33,000 is for capital equipment or hardware.

The drill being developed under this contract is for medium-hard and hard rock as opposed to those which might be used in soft formation tunnels. Medium-hard rock may be defined, loosely, as that which has a compressive strength of 10,000 to 20,000 psi and hard rock as that in excess of 20,000 psi in compressive strength.

The purpose of the probe drill is to forewarn the owner and/or tunneling contractor of impending difficulties such as bad ground requiring roof support, water inflow, or gas. Such forewarning will permit corrective measures to be taken in advance which will lead to greater economy, improved speed of tunnel advance and safety in underground excavation. Such a horizontal drilling capability may also be useful in pre-job planning and estimating.

The development of TBMs within the last decade and the prospects for their future development point toward a very serious need for advanced knowledge of ground conditions which can be provided by probe drills. These TBMs have an existing potential for drilling 200 feet of tunnel per day in medium-hard rock and in excess of 100 feet per day in hard rock. There is some speculation that this capability may be advanced substantially by research. A probe drill, to be effective, must be able to drill faster than the TBM as it may be required to start several tens of feet in the rear of the machine and overtake it. It should then be able to drill faster than the TBM and to project the probe hole for a distance of at least three or four days in advance of the machine's activity.

Direction control for the probe drill is going to be very critical. It must be close enough to the projected tunnel to be significant but should not interfere with the machine.

One of the most serious problems in developing a probe drill will be handling the drill rod. Drill rod handling often consumes more time than the drilling in normal underground small-hole horizontal drilling.

It has been decided that it will not be necessary to take cores all the way, but only on an intermittent basis. Core drilling is slower than some forms of full-hole drilling.

This study has (by extending results of some previous studies) evolved a method for handling drill rod intact and stored on the ground. The drill rod is stored along the line of the tunnel in the rear of the drill in a pipe or in a previously drilled hole, as is illustrated in Figures 1 and 2. The drill rod can be extracted from the hole very rapidly by a rod extractor which has been designed on this contract and is shown in Figures 3 and 4. This will withdraw the drilling rod from the hole, for changing drilling methods, at the rate of 180 feet per minute or in less than 10 minutes for 1,000 foot of drill rod.

The ground storage method envisioned also provides for a unique drilling fluid circulation system as can be seen in a thorough analysis of Figures 1 and 2. No swivel is required.

Equipment is being ordered for field testing these concepts in quarries of rock representing those types under consideration in this contract. Delivery of most equipment is expected by the end of November and this contract may be completed by December 31st, two months ahead of schedule and within the original cost estimate.

2.0 TECHNICAL APPROACH

Several drilling methods were considered. It was decided that the best way to drill the specified rock types at a satisfactorily rapid rate was with a down-hole percussion drill, except during the coring parts of the cycle. Diamond rotary drills can run down-hole percussion drills of small diameter and, of course, can run the diamond core barrel at the selected intervals.

It was decided that cores would be taken in five-foot lengths every 45 feet. The 45 feet of hole between these five-foot cored segments would be drilled with a 3-1/2 inch diameter down-hole percussion drill using a 4 to 4-1/2 inch diameter full-hole bit. These

down-hole percussion drills consume about 200 cubic feet of air a minute necessitating air compressors which will be rented for the tests. These drills will drill medium-hard rock at the rate of 30 to 35 feet per hour and the hard rock at 15 to 20 feet per hour. These drilling rates are about twice the instantaneous penetration rates of TBMs. If direction and rod-handling problems are solved, they should be able to overtake and precede the boring machines satisfactorily.

Diamond drills will drill cores (using water circulation) at about half the penetration rate of the down-hole percussion drills. Just to be sure that wireline core drilling is or is not faster than the proposed percussion drill, a test using the wireline technique with conventional swivels, etc., will be tried. Tests with other proven drilling methods such as rolling cutter bits or turbines will be considered for trial. The so-called "exotic" or "novel" drilling techniques such as thermal drills or high-pressure water will not be tried, but the drill set-up may be made available to investigators in those fields.

3.0 PRINCIPAL PROBLEMS

The major problem in the drilling test probably will be in hole direction control. It is believed that by using several techniques of wedges and stabilizers that the hole can be prevented from either drooping or climbing. Reversing rotation may be the answer to preventing excessive wandering of the bit to the right or left. Continuous monitoring may be necessary to prevent excessive hole deviation from either mechanical effects of drilling or of dips or other peculiarities of the rock. The holes will be surveyed using commercial surveying methods and rented tools from such companies as Eastman, Sperry Sun, or E. V. Kuster.

There is another problem in the ground storage scheme and that is drill rod unscrewing itself in rear of the drilling rig. In order to have drill pipe trailing the hollow spindle drill, and not unscrewing itself (which may also occur in reverse rotation) a resin will be applied to the threads which can only be removed with the application of heat and torque.

4.0 DRILLING ANALYSIS

TBMs currently can make maximum instantaneous penetration rates of 17 feet per hour in the medium-strength rock (MSR) and about half that fast in the high-strength rock (HSR). Some of these machines consistently make 200 feet per day in the MSR and perhaps a hundred feet per day in the HSR.

A goal has been set for the probe drill to precede the tunnel borer by four to five days. This means that it should have a depth capacity of at least 800 to 1,000 feet in MSR and of 400 to 500 feet in HSR. Most of the drill criteria used in this study has been established assuming a 1,000 foot capacity in either type of rock.

Most TBM operations bore rock in three shifts, daily, five days a week. They do major maintenance, including changing cutters, on the two non-boring weekend days.

Four methods of locating the probe drill have been considered. They are:

- A. Mounting the probe drill in the center of the TBM so that its drilling can proceed simultaneously with that of the machine. This has the advantage of making a probe drill which only has to maintain an advance rate equal to that of the TBM. On the other hand, it has two very serious overriding disadvantages which rule it out as a practical approach for the near future. The first of these disadvantages is that it would require a major redesign of TBMs. The second is more serious in that any deviation by the TBM or probe drill, planned or unplanned, would create interference between the TBM head and the probe drill rod.
- B. Drilling the probe hole ahead through a window not in the center of the head of the TBM and used by shutting down the machine for all, or part, of a shift each day. In most cases such interruption to production would be most undesirable.
- C. Drilling the probe hole through a window in the head of the TBM while it is shut down for weekend maintenance. Some of this maintenance requires that the cutterhead be rotated a few times so that probe hole drilling would be interrupted, occasionally. The drill would need to have a rather high drilling rate capacity to maintain its lead in the few hours available to it each week.
- D. Drilling the probe hole from alcoves, cut into the wall of the tunnel, at about 1,000 foot intervals. These alcoves would have to be cut, or blasted, just in back of the machine on a weekend. See Figures 1 and 2. They would,

In effect, be a "shelf" deep enough for the hole not to wander into the path of the TBM. The drill would have to be capable of drilling slightly faster than the TBM. It will require very close guidance control. Perhaps this guidance of the probe holes is beyond the current state-of-the-art and may become one of the primary goals of this research. The alcove approach will not provide for taking a sample in the direct path of the TBM but it would be close enough for all practical purposes and appears to be the best method suggested to date.

Using the previous as a guide, a criteria has been established for a drilling rate for the probe drill to provide 300 feet per 24-hour day in MSR and 150 feet per day in HSR.

The size of probe hole depends on the availability and reliability of tools and methods as well as drilling rates and results. It was assumed early in the study that it may not be essential to have a continuous core throughout the full length of the bore hole. An assumption was made that a five-foot long core every fifty feet would be adequate. On the other hand, it was recognized that any apparent change in rock formation, indicated by change in penetration rate, or changes in torque or cuttings, should signal the need for a core, even though 45 feet of open hole had not been drilled.

It was recognized that, if diamond drilling proved to be the best method of drilling all of the hole, core drilling could prove to be the fastest and cheapest method even though cores were not required all the way. This will be evaluated as a back-up or substitute system using a wireline core barrel.

Determination of core size was made on the basis that some laboratory analyses might need a core of sufficient diameter to cut at least one-inch square cross section from it. This indicated the need for a B size core as a minimum.

There is not enough information available in the literature on drilling horizontal holes of this length in rock to be able to calculate precisely the torque requirements or torque capacity of different sizes of available rods. That is part of the reason for the need for the research being planned. The tendency in such a selection, which must be made on

judgement, is to choose the largest standard rod size, to be "safe," and then back off to a smaller size if tests show an over-design. This would call for an "K" size rod or larger. On the other hand, there are many advantages to keeping all tools used underground as light as possible and hole sizes as small as may be safe and economical.

Results of the Bureau of Mines' work were available wherein they had drilled rather deep 3-inch diameter holes in coal with drag bits. At least one of these holes went to 503 feet depth. It is well known that drag bits in a soft formation, such as coal, result in greater torsional stresses than diamond bits or percussion drills in hard rock. B-X-casing was used as drill rod by the Bureau and this is 1.8125 inch diameter. With this knowledge, it seemed to be a safe calculated risk to use "B" size wireline drill rods which are 2.25 inch O.D. It was recognized that a few rods of slightly larger or different configurations may be necessary at the forward end of the rod system (near the bit) for maintaining hole direction and stability.

Various drilling methods were considered and evaluated as shown in matrices in Figures 5 and 6. From this, and practical experience in the field, it appeared that diamond drilling with water has the best chance of success for the coring. The fastest and best-rated method for full-hole drilling between coring sequences is the down-hole percussion drill.

The smaller down-hole percussion drills are about 3.5 and 4.5 inch diameter and each of these drills a hole about one inch larger than the tool. These will penetrate MSR at 15 to 20 feet per hour and MSR at about 30 feet per hour. Currently the choice appears to be the smaller tool as that hole size will require 200 cfm to operate the drill and transport the cuttings out, whereas the larger drill's requirements might be double this. The 4.5 inch hole made by a 3.5 inch tool should easily be reamed to that diameter from the 2.36 inch "B" core hole and not result in squeezing the percussion bit which is a common cause of failure while reaming with this type of tool when they do not have enough shoulder in which to ream adequately.

Some concern has been expressed that lost circulation of drilling fluid may be a problem in some formations. It should be noticed that this problem is a potential one. With the drilling method proposed, however, only 10% of the drilling will be done with water. If such a problem does exist, it is less with the proposed system than with any system which would use water for all of the drilling.

Air circulation systems will be used with 90% of the drilling which will be done by percussion. Air systems occasionally are troubled by lost circulation, but it is rare and if conditions are that bad, the probe drill won't be needed as badly anyway. In such bad conditions, the tunneler will be prepared for implementing the ultimate in ground support.

If lost circulation conditions are encountered, they may be overcome by mud additive techniques which are common to the oil well drilling industry. It is not believed they are as likely to be as frequent a problem in horizontal drilling as they are in vertical drilling sedimentary formations where many different formations must be intersected.

It has been suggested that a casing may be required in the trailing hole in lost circulation conditions. Some concern has been expressed that this casing will wear with the rod laying on its bottom and rotating. In the condition where the hole must be cased, the stored part of this drill rod will be rotating only in a few hundred feet of the forward end of the casing. If necessary, the casing can be protected by teflon pillow blocks or other coatings in the pipe or on the rod. It is believed that a lubricant injected in the air or water would minimize the wear adequately.

It appears that the more serious wear problem will be the wear of the drill rod rotating in the bare rock hole ahead of the drill. Here again, the proposed drilling method will provide much less wear to the drill rod than nearly any other drilling method likely to be successful. This is because the percussion drill which will do 90% of the work requires a rotary speed of only 15 to 25 rpm while normal diamond rotary drilling requires several hundred rpm. The only drilling method requiring less rotary speed is the turbine or in-hole fluid motors and these will be tried. It is unlikely in-hole motors will be as fast as percussion drills because they must be used in this application with diamond bits which would be essential as they require low thrust and they are usually slower than percussion drills. This turbine or in-hole motor method also results in water circulation all the way and their maintenance and operating cost is very high.

5.0 SITE SELECTION

Several geographic areas in the U.S. were examined as potential field test drilling sites. The first tests will be conducted in rock quarries. These should be in large active quarries where the drilling can be in an area out of the way of current production. The active quarry is desirable because much equipment may have to be left for some periods of time

and its security will be better assured than in an inactive quarry. The principal search for quarry sites evolved to the California and Virginia areas. Virginia had the advantages of a greater variety of consistent rock, more receptive quarry owners and much better labor and per diem rates. California had the advantage of better weather conditions and a closer proximity to the Jacobs' establishment, which will save travel time. It should be mentioned that there are drive-in underground quarries available in West Virginia which would overcome the weather objection to that part of the country. It has been decided that the test will be run in California unless there are unforeseen developments.

For the first test a good hard rock quarry site has been selected at Granite Stone Company near Watsonville, California, which is about 120 miles south of San Francisco. This is in a granite which appears to have a compressive strength in excess of 20,000 psi. There are several limestone quarries in the same area and these are being examined for the medium rock tests to follow. An assembly area has been chosen for the equipment at the Person Western Company, 1028 Carolan Avenue, Burlingame, California.

6.0 EQUIPMENT SELECTION

Quotations have been received from rotary diamond drill manufacturers. A Sprague & Henwood Model 40-CL drill, Figure 7, with hydraulic drive has been selected and ordered. A "B" type wireline drill rod has been chosen, based on analysis of the problem and the recommendation of several suppliers. The apparent low bidder for this drill rod item is the Longyear Company and permission is being requested to place an order with them. Quotations for other major items of equipment including the rod extractor, ground storage drill pipe, water pump, and other auxiliary tools have been evaluated. It is hoped to place orders for all of the major equipment before the end of September. Delivery is being sought prior to the end of November.

7.0 INSTRUMENTATION

This drilling device will be completely instrumented. An Airpax magnetic pick-up will be used as a tachometer and as an instrument for penetration rate. These will be tied into a Rustrak recorder. See Figures 8 and 9. An alternate method of recording penetration rate using a DC transducer, Figure 10, is being considered.

An American Meter Company recorder will be used to measure and record thrust and hydraulic pressure to the rotary hydraulic motor and the mud system. This is a three pen (different colored ink) wind up eight hour 12 inch disc system for pressure ranges of 0 to 2000 psi as required.

See Figure 11. A flow meter will be used for measuring the hydraulic fluid volume into the rotary hydraulic motor (Figure 12) and another similar system will be used for the drill mud volume. These volumes also will be recorded on a Rustrak device. Some of this instrumentation has been ordered and the balance should be ordered in September. A general arrangement of instruments (less recorders) is shown in Figure 13.

8.0 FUTURE PLANS

Final analysis of the instrumentation package will be completed during September.

During September and October, final arrangements will be made with quarries for field testing.

It is absolutely urgent that Phase II of the contract covering actual field tests be expedited as it appears that Phase I will be completed at least two months in advance of the contract schedule. In order to avoid extra costs and delays, it is very desirable that Phase II plans be made as soon as possible.

9.0 COSTS

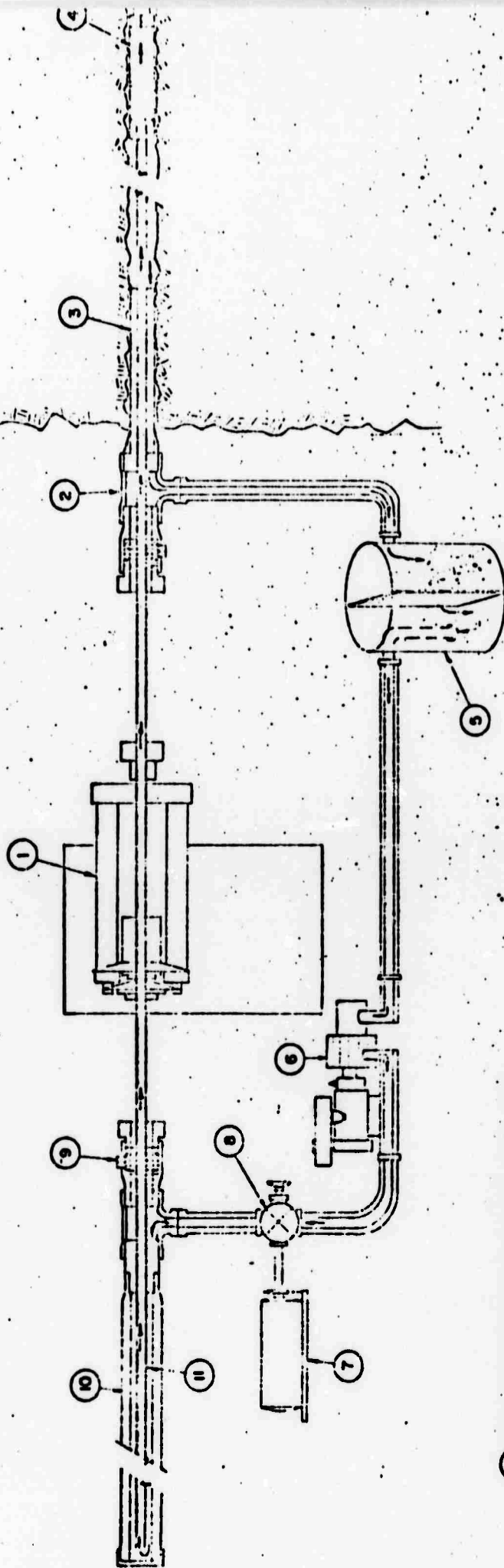
It appears that the costs of Phase I will be within the original estimate.

Expenditures for the first six months, through August 31, 1971, are tabulated below:

Man Hours	861
Fees Expended	\$16,644.82
Fee Earned	<u>1,000.10</u>
Total	\$17,644.92

Figure 14 illustrates the estimated rate of expenditure versus the actual rate and the revised projection based on an early completion date of the contract.

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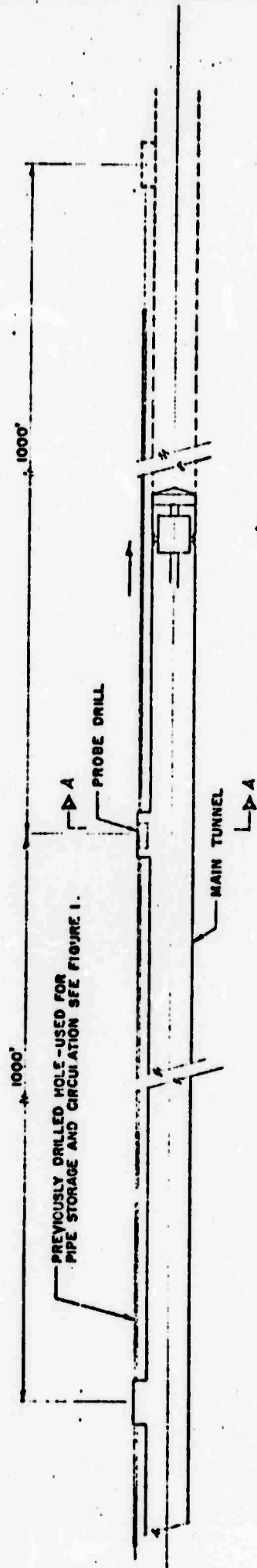
- (1) SPRAGUE & MENWOOD MODEL 40-CL DRILL
- (2) STUFFING BOX - LONGYEAR NO. 17393
- (3) HW CASING 5' LONG, 4" I.D., 4 1/2" O.D.
- (4) IN-HOLE PERCUSSION DRILL-MISSION B-32-40
- (5) SEPARATING BOX - CUTTINGS, WET OR DRY
- (6) PUMP (GASOLINE ENGINE DRIVEN) APPROX. 30 GPM
- (7) AIR COMPRESSOR - 360 CFM - 125 PSI
- (8) TWO-WAY VALVE
- (9) STUFFING BOX - SEE (2)
- (10) N.W. CASING 1000' LONG, 3" I.D., 3 1/2" O.D.
- (11) BW ROD 1100' LONG, 1 13/16" I.D., 2 1/8" O.D.

NOTES:

1. EQUIPMENT SPECIFIED IS TENTATIVE SELECTION ONLY. FINAL SELECTION TO BE MADE LATER.
2. PERCUSSION DRILL CAN BE REPLACED AS REQUIRED WITH DOUBLE TUBE SWALLOW TYPE CORE BARREL - 5' LONG - LONGYEAR JV NO 26672
3. RAPID ROD RETRACTOR BETWEEN DRILL 1 AND STUFFING BOX 2 - NOT SHOWN. DRIVE WILL BE BY OPPOSED WHEELS, NON IN DESIGN.

GROUND STORAGE OF DRILL ROD FOR U.S. BUREAU OF MINES, ARPA

FIGURE 1



NOT REPRODUCIBLE

PROBE DRILL ARRANGEMENT
FOR
U.S. BUREAU OF MINES, ARPA

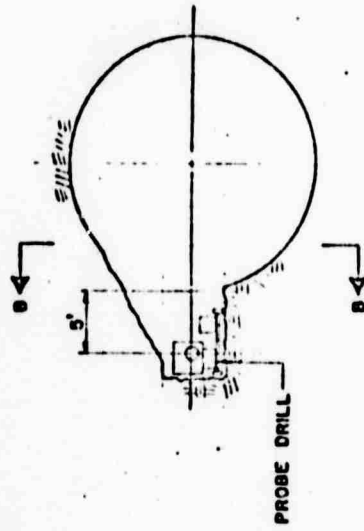
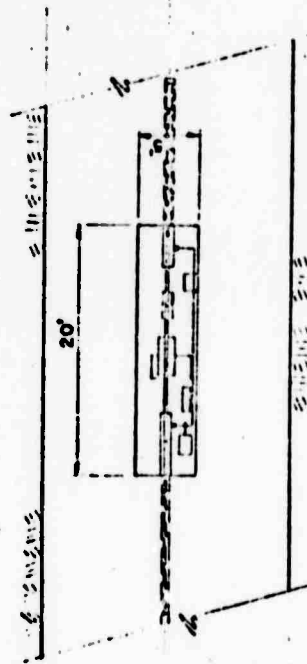


FIGURE 2

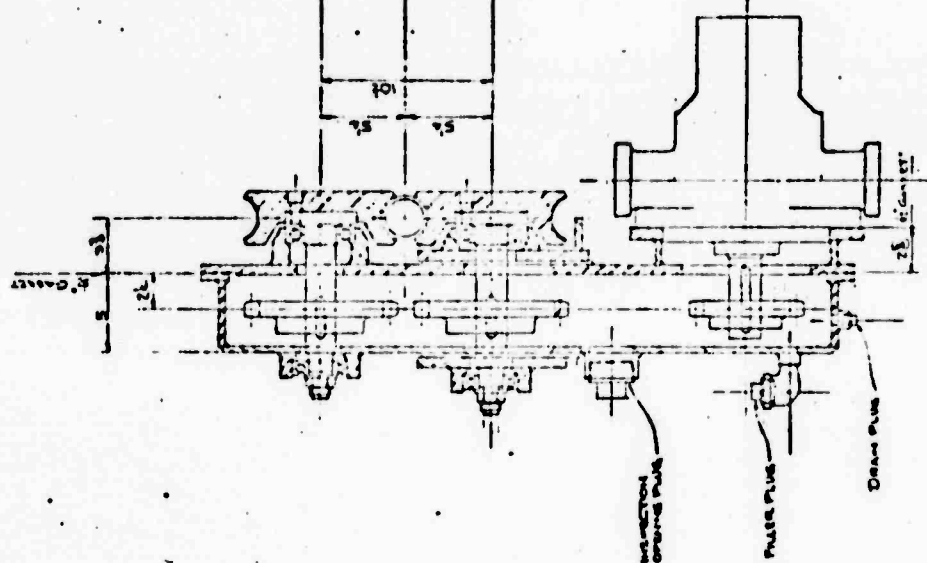
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U.S. BUREAU OF MINES - ARDA
COAL MINE EMPLOYMENT
DRILL ROD IN-OUT LIVER
CENTRAL ARRANGEMENT

JACOBS ASSOCIATES
CONSTRUCTION ENGINEERS
300 BANSOME STREET
SAN FRANCISCO

FIGURE 3

100-5
1902-225



SECTION A IN DRAWING POSITION

SECTION 5

JACOBS ASSOCIATES
CONSTRUCTION ENGINEERS
800 BANSOME STREET
SAN FRANCISCO CALIF 94103

U.S. BUREAU OF MINES - 1900
LONGMONT COLORADO DEPT. OF
DEVELOPMENT
DEPT. OF THE INTERIOR
GENERAL AGREEMENT

11007. 3 2nd. 11 10 201
11008. 3 2nd. 11 10 201
11009. 3 2nd. 11 10 201

FIGURE 4 •

Drill Method Selection

DRILL METHOD	Diamond		Rolling Cutter	Percussion			Turbine	In-hole Motor	Thermal	Water Jets
	Core	Plug		Reg.	Rotary	In- Hole				
<u>PARAMETER</u>										
A- Thrust Needs	100	80	10	50	50	90	50	50	100	100
B- Hole Siz	100	100	40	100	60	70	50	80	90	60
C- Depth Capability	100	100	100	30	10	90	100	100	80	90
D- Power Needs	50	40	90	30	30	40	30	30	50	50
E- Coring Ability	100	0	20	20	10	40	50	50	0	0
F- Pen. Rate HSR**	70	60	70	90	100	100	80	80	80	40
G- Pen. Rate MSR*	50	50	90	90	70	70	80	80	40	80
H- Eqpt. Compactness	60	80	40	90	70	80	80	80	60	60
I- Skill Required	70	70	70	80	60	60	40	40	50	40
J- Economics	80	70	90	40	40	70	50	60	40	40
K- Direction Stability	60	60	90	40	40	70	70	70	80	80
L- Safety	100	100	100	100	100	100	100	100	40	50
M- Direction Control	60	60	80	50	50	60	90	90	80	80
N- Adaptability to Rock Changes	90	90	100	100	90	100	80	80	50	60
O- Operation Delays	60	100	100	100	100	100	100	100	100	100
P- State of Technology	90	90	100	100	60	70	60	70	60	50
GRAND TOTAL	1260	1150	1170	1110	940	1210	1110	1160	960	980
Total Coring MSR*	1190	NA	1100	1020	740	1110	1030	1080	NA	NA
Total Coring HSR**	1210	NA	1080	1020	870	1140	1030	1080	NA	NA
Total Full Hole MSR*	1090	1090	1080	1000	820	1070	980	1020	880	940
Total Full Hole HSR**	1110	1100	1060	1000	860	1200	980	1020	920	900

* Medium Strength Rock

** Hard Strength Rock

NOTE: Rated 0-100 with 100 best

Figure 5

DRILL CHOICE (FROM MATRIX, FIG. 5)

D R I L L I N G M E T H O D									
	C O R I N G						F U L L - H O L E		
	Medium Rock		Hard Rock		Medium Rock		Medium Rock		Hard Rock
	Method	Score	Method	Score	Method	Score	Method	Score	Method
1	Diamond Core	1190	Diamond Core	1210	Diamond Core	1090	In-Hole Perc.	1200	In-Hole Perc.
2	In-Hole Perc.	1110	In-Hole Perc.	1140	Diamond Plug	1090	Diamond Core	1110	Diamond Core
3	Rolling Cutter	1100	In-Hole Motor	1080	Rolling Cutter	1080	Diamond Plug	1100	Diamond Plug
4	In-Hole Motor	1080	Rolling Cutter	1080	In-Hole Perc.	1070	Rolling Cutter	1060	Rolling Cutter
5	Turbine	1030	Turbine	1030	In-Hole Motor	1020	In-Hole Motor	1020	In-Hole Motor
6	Reg. Perc.	1020	Reg. Perc.	1020	Reg. Perc.	1000	Reg. Perc.	1000	Reg. Perc.
7	Rotary Perc.	740	Rotary Perc.	870	Turbine	980	Turbine	980	Turbine
8	Diamond Plug	NA	Diamond Plug	NA	Water jets	940	Thermal	920	Thermal
9	Thermal	NA	Thermal	NA	Thermal	880	Water jets	900	Water jets
10	Water jets	NA	Water jets	NA	Rotary Perc.	820	Rotary Perc.	860	Rotary Perc.

Figure 6

Henwood 40-C--40-CL Core Drills

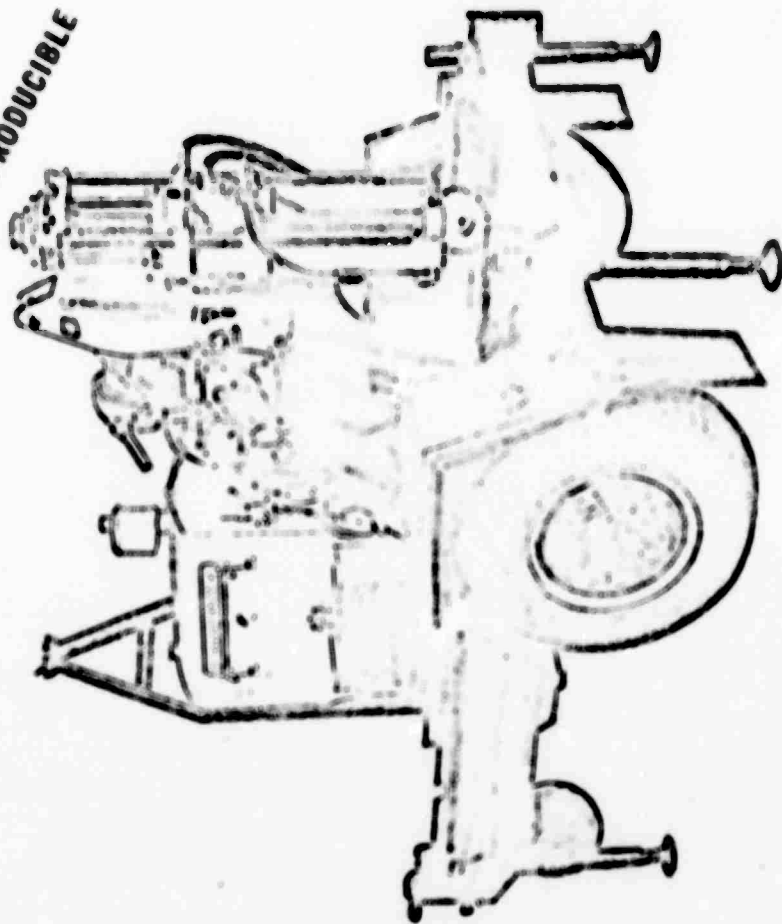
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TRAILER MOUNTINGS

Low-Bed Type

The 40-CL skid-mounted unit becomes a highly mobile drill when used in conjunction with a special trailer. The trailer is designed so that the drill machine can be operated directly from the trailer or the drill can be removed and operated as a skid unit.

The trailer is sturdily constructed, using structural steel members throughout. Four screw-type leveling jacks are provided—one at each corner of the trailer to insure a stable, level working platform for the drill unit. The low bed type trailer can be furnished in both 2-wheel and 4-wheel types equipped with electric brakes, and diamond deck plate fenders on special order. (See illustration at right.)

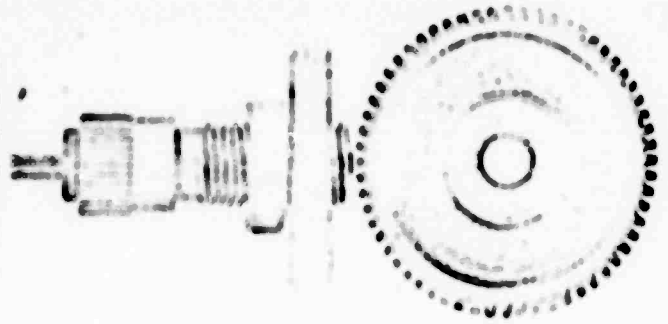


Sprague & Henwood Model 40-CL Drill

Figure 7

PICKUPS AT WORK

AIRPAX magnetic pickups are most often used with toothed gears. Any magnetic discontinuity will do, such as holes or rivets. Sometimes it is convenient to use fractions or multiples of 60 (a 60 tooth gear delivers 100 cycles per second at 100 revolutions per minute). Airpax tachometers permit any tooth combination which will provide a frequency of 5 cycles per second or higher. Figure 1, shows the mechanical arrangement of pickup, bracket and gear.

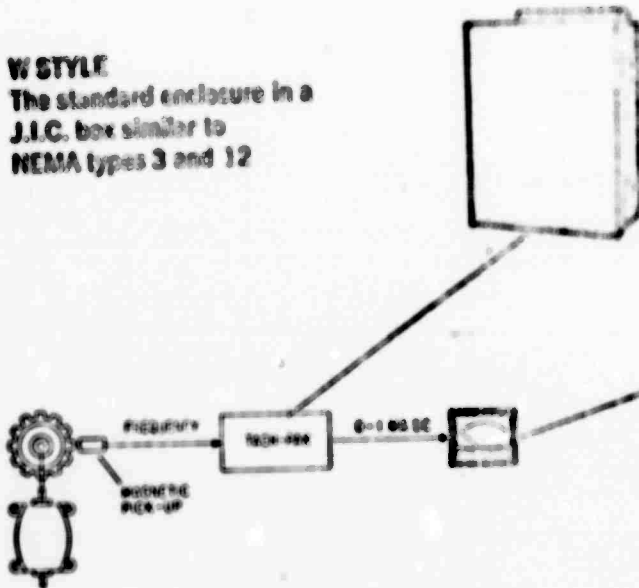


AIRPAX

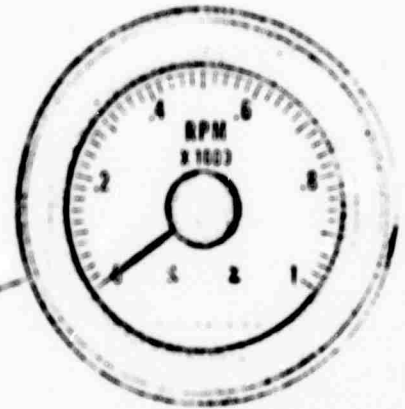
MODEL 310

W STYLE

The standard enclosure in a J.I.C. box similar to NEMA types 3 and 12



RPM MEASUREMENT

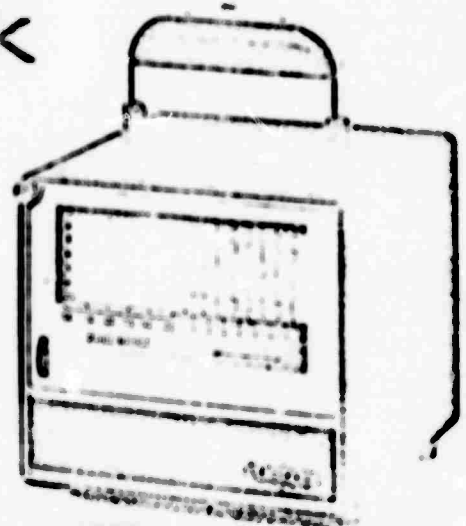


The rugged Model 310 offers a 250° arc scale having a length $2\frac{1}{2}$ times that of standard 90° meters. The meter movement is 0.1 MA DC full scale. Accuracy is 2%. Meter resistance is 200 ohms $\pm 10\%$. Scale diameter is 2.75 inches.

rusttrak

SPECIFICATIONS:

- Inkless, dry writing, rectilinear recording on pressure-sensitive paper.
- Wide range of sensitivities, writing and chart speeds. AC or DC drives available.
- Usable chart width $2\frac{1}{4}$ " except Model 391 (1" per channel), and Model 3146 (2").
- Quick easy chart review and rewind. Sliding access window.
- Custom scales available.
- F204 Controller and F137 Two-Point Time
- Accuracy $\pm 2\%$ of full scale.
- Case size: $6\frac{1}{2}$ "W, $6\frac{1}{2}$ "D, $5\frac{1}{2}$ "H.
- Weight: Approximately 6 lbs.
- Most specifications in series 200 are standard in series 300.

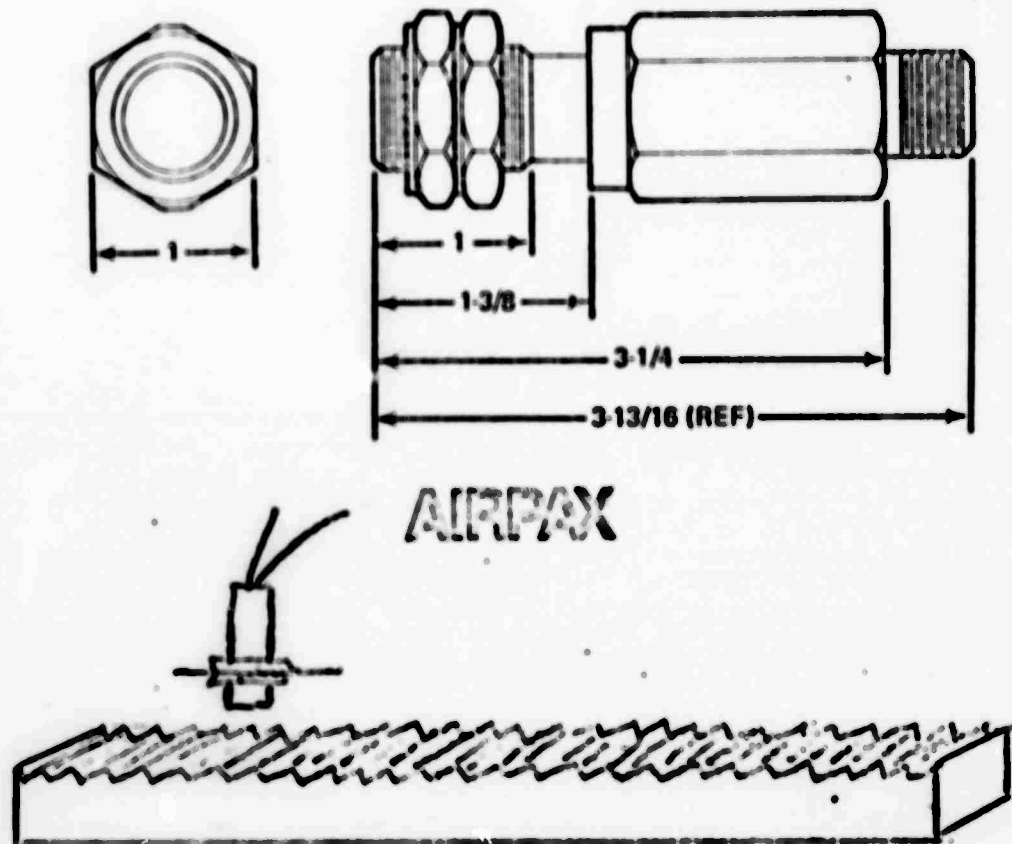


MODEL
3133/392-8
SHOWN

RPM Measurement System

Figure 8
- 19 -

The standard Model 4-0001 Zero-Velocity Digital Pickup is contained in a splashproof and dustproof machined housing. Two mounting locknuts are provided to facilitate installation and alignment of the pickup.

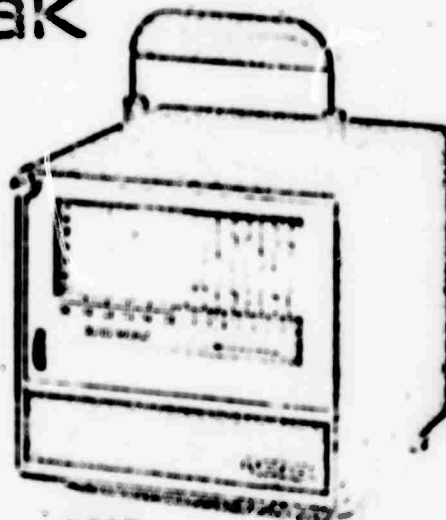


RACK GEAR - PICK UP

rusttrak

SPECIFICATIONS:

- Inkless, dry writing, rectilinear recording on pressure-sensitive paper.
- Wide range of sensitivities, writing and chart speeds. AC or DC drives available.
- Usable chart width 2 3/8" except Model 391 (1" per channel), and Model 3146 (2").
- Quick easy chart review and rewind. Sliding access window.
- Custom scales available.
- F204 Controller and F137 Two-Point Time
- Accuracy $\pm 2\%$ of full scale.
- Case size: 6 1/2" W, 6 1/2" D, 5 1/2" H.
- Weight: Approximately 6 lbs.
- Most specifications in series 200 are standard in series 300.

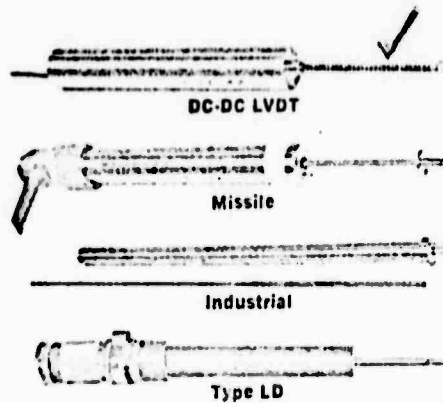


MODEL
3133/392-B
SHOWN

Penetration Measurement System

Figure 9
- 20 -

SRC DIVISION



DESCRIPTION

Linear transducers provide a voltage output which is linear with the movement of a permeable probe along the instrument bore. The magnetic circuit can be provided as either a 4-wire differential transformer or a 3-wire variable inductance. DC-DC Linear Transducers are available, such as the D1110 with an accuracy of better than .1%. Displacement of the probe creates an unbalance in the transducer coils, resulting in a "high level" output voltage proportional to probe movement.

FEATURES

ACCURACY • LINEARITY • AC OR DC
• RUGGED LOW FORCE REQUIREMENTS
• LIGHTWEIGHT •

TYPICAL APPLICATIONS

Missile engine monitoring • measurement and control • cam following • checking bearing contour • sensing diaphragm movement • extensometer micrometers • instrument translators • breakaway mechanisms • control

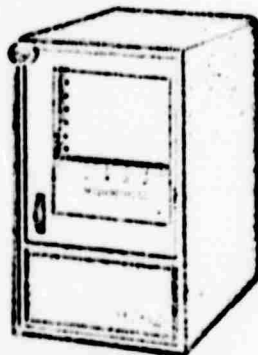
pitch and yaw • monitor aircraft control surface actuators (F-14 & F-15) bellows movement • piston motion • position sensors • scale beams • meter movements • analytical balances • nuclear/seismic motion measurement •

PHYSICAL CHARACTERISTICS

Displacement Ranges: 0.01 to 50 inches.
Temperature Ranges: -160° to +450°F typical.
Shielding: Magnetic and electrostatic.
Thermal Coefficient of Sensitivity: 0.02% per degree F nominal.

ELECTRICAL PERFORMANCE RANGES

Excitation: Frequency: 60Hz to 20kHz.
Excitation Voltage: Up to 115 VAC.
Sensitivity: Up to 60 v/v/inch.
Linearity Range: ± 0.1 to 1%.
Null Voltage: 0 to 3 mv/v.
Resolution: Continuous.
Repeatability: 0.01% typical.
PRICE RANGE: \$75 to \$250.



MODEL 288

rustrak

SINGLE CHANNEL DC RECORDER MODEL 288

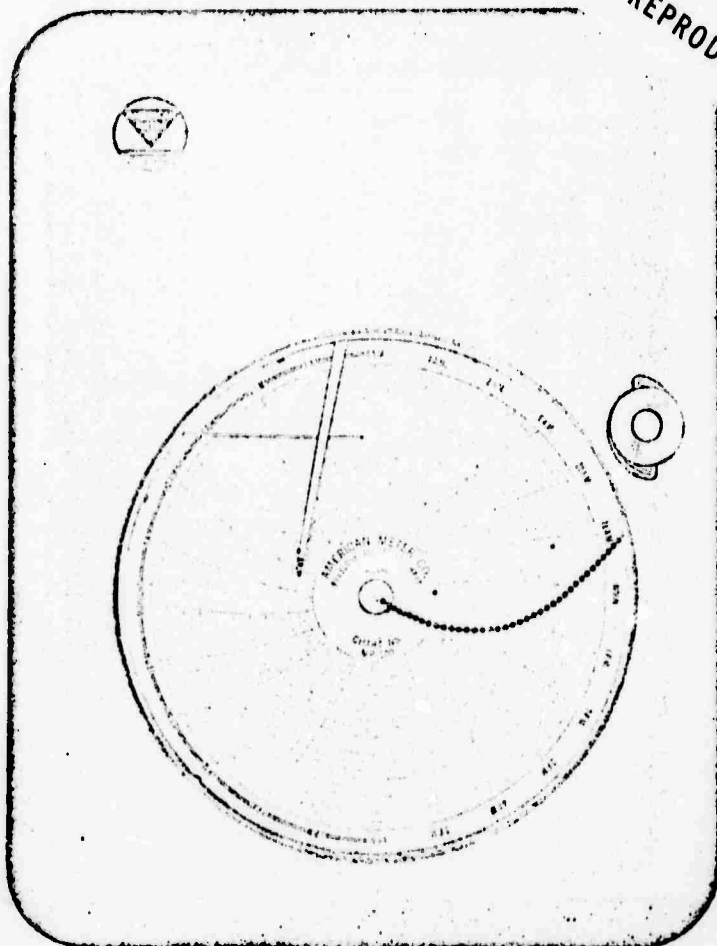
This versatile instrument is the basic recorder of the Rustrak product line. Available ranges are shown in Table 1. Usable chart width: 25 1/16".

Alternate Penetration Measurement System

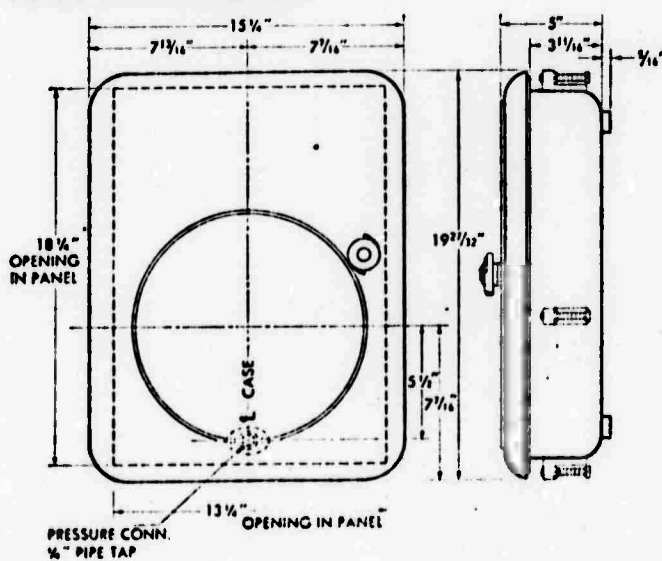
Figure 10

- 21 -

NOT REPRODUCIBLE



standard case dimensions



American® Pressure Recorders

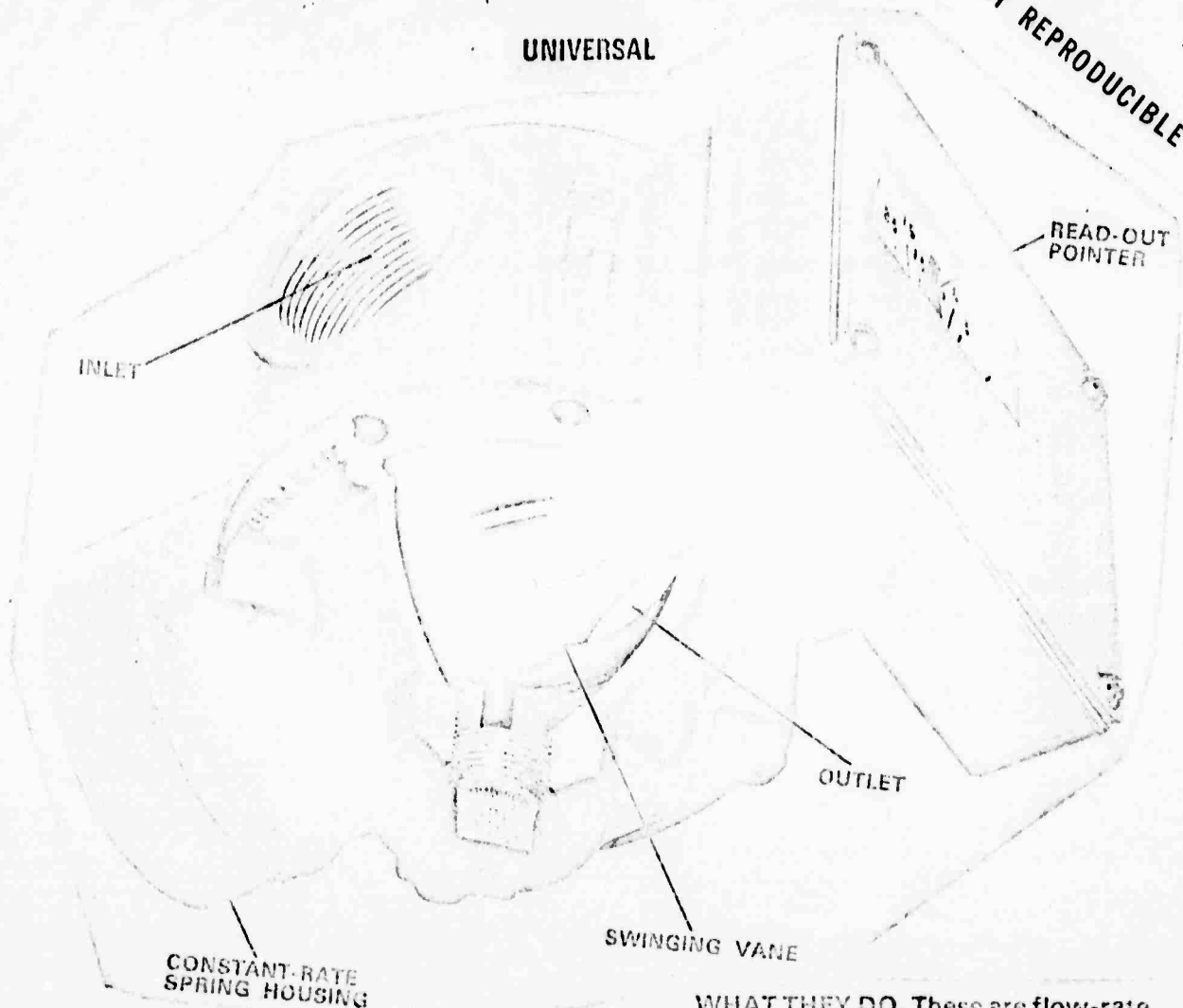
Hydraulic System's Pressure Recorder

Figure 11

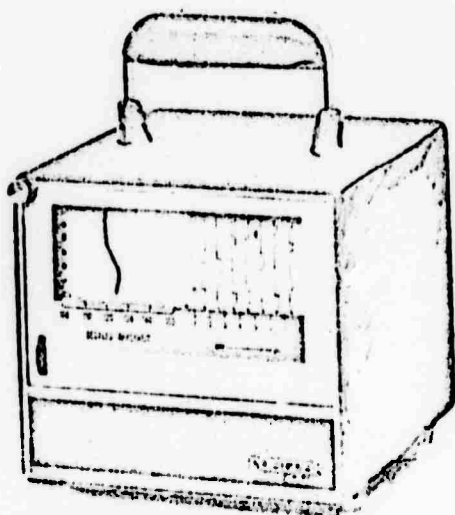
- 22 -

UNIVERSAL

NOT REPRODUCIBLE



WHAT THEY DO. These are flow-rate indicators and switches that consistently and continuously monitor the rate of flow, in gallons per minute (or equivalent), of liquids passing through them. If the flow-rate varies or stops, the change is immediately apparent on the indicator dial (and signalled, through a switch model).



MODEL
3133/392-8
SHOWN

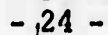
rustrak

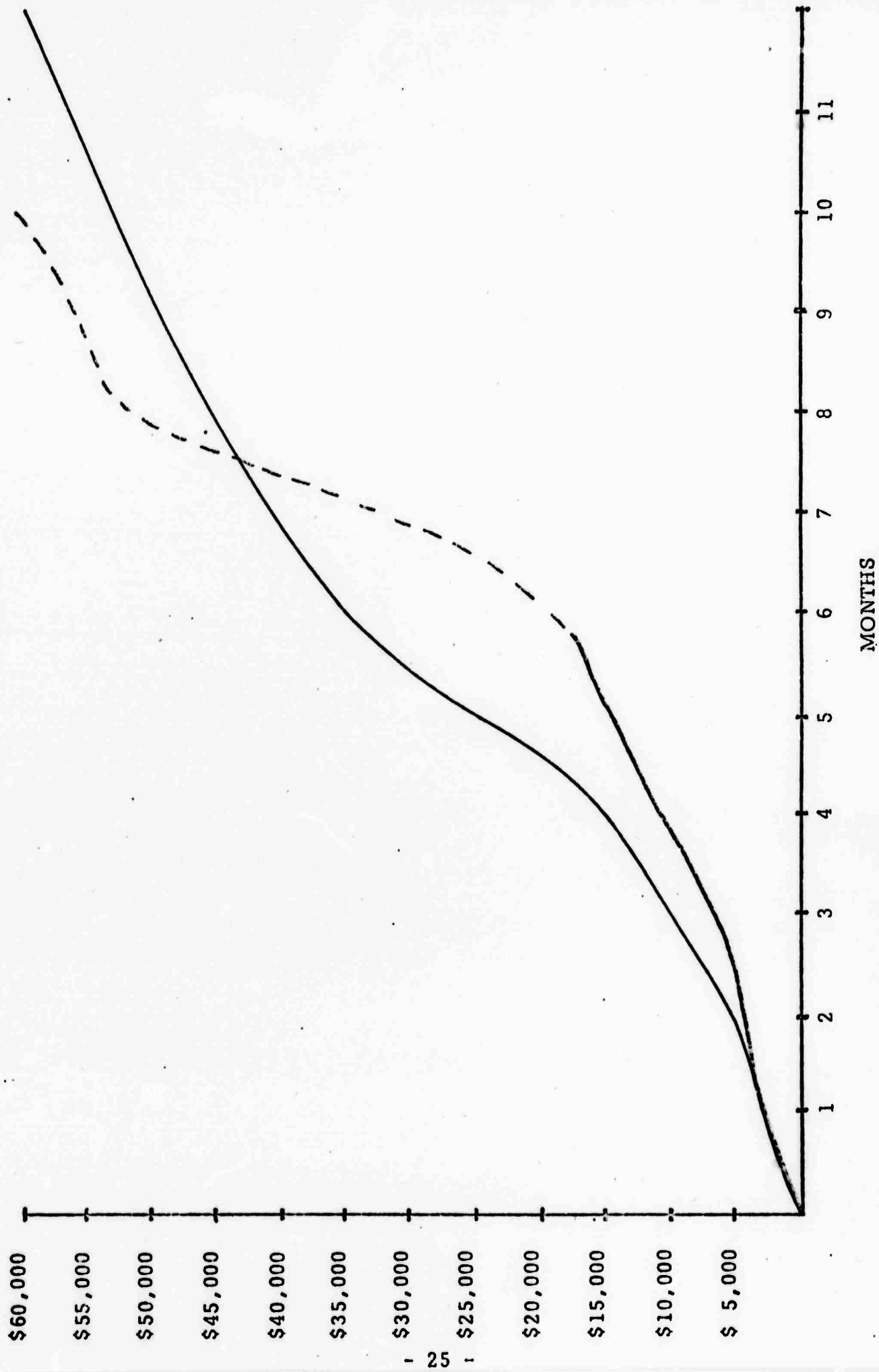
SPECIFICATIONS:

- Inkless, dry writing, rectilinear recording on pressure-sensitive paper.
- Wide range of sensitivities, writing and chart speeds. AC or DC drives available.
- Usable chart width $2\frac{3}{4}$ " except Model 391 (1" per channel), and Model 3146 (2").
- Quick easy chart review and rewind. Sliding access window.
- Custom scales available.
- F204 Controller and F137 Two-Point Time

Fluid Volume Measurement System

Figure 12





Actual Dollars Expended (—) vs. Estimated Dollar Expenditure (---)
Revised Projection of Dollar Expenditure (---)
Figure 14